# Changes in Great Valley Vernal Pool Distribution from 1989 to 1997.

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## Table of Contents



## List of Figures



## List of Tables

## 1. Introduction

Literally dozens of sensitive plant and animal species in California are associated with vernal pool habitats: at least four separate conferences have focused on the habitat since 1976 (Jain 1976, Jain and Moyle 1984, Ikeda and Schlising 1990, Witham et al. 1998). In spite of all this interest, detailed understanding of the habitat's distribution through out the Great Valley has remained elusive. The only published survey to cover the entire Great Valley (Holland 1976) was prepared in 1973 and 1974 from air photos no more recent than 1972. This early survey also suffers from low resolution (1:500,000 scale) and rudimentary cartographic sophistication.

Over the past three years, I have remapped the distribution of Great Valley vernal pools using modern cartographic techniques, including Geographic Information Systems, under contract with the US Fish and Wildlife Service (Holland 1998). This remap used vertically oriented, true color air photos to map surviving habitat complexes onto standard 1:24,000 USGS topographic quadrangles. These polygons were digitized using an Arc-Info based GIS and have been assembled into a synoptic data layer.

This study builds upon the recent remap in an important way. The recent remap, like its 1976 predecessor, suffered because it utilized photography spanning nearly a decade. By exploiting the capabilities of modern GIS, I was able to assemble imagery at precisely the scale of an available 1997 U2 flight covering virtually all of the remapped area. Thus, I was able to update the entire map to July, 1997 conditions. While U2 imagery is of insufficient scale (1:130,000) for initial mapping, it is sufficient to see any changes in land use. This report describes how the imagery was prepared and examines for each of the 30 counties included in the study area the rates at which habitat loss is occurring.

## 2. Methods

The 1996 remap utilized a series of slide images acquired over the years by a program in the California Department of Water Resources that monitors the production, distribution, and utilization of irrigation water through out California. This program uses a specially-equipped aircraft that takes true-color, vertically-oriented 35mm slides along systematically placed flight lines that assure complete coverage of the agriculturally important lands of California. The slides are used to map types of water use on fields down to one acre in size. This program operates five regional offices, three of which (Red Bluff, Sacramento, and Fresno) incorporate the present study area. Each regional office flies one or two counties (depending on their size) each year; each county is reflown every 5-7 years.

These slides can be projected at any scale. After experimenting with several approaches, I settled on a "display projector" as the optimum solution to conflicting needs for resolution, image brightness, and ability to work in a lighted room. This device projects slides, not on a wall, but on a television-like screen on the front of the unit. It projects the slides at roughly 1:10,400 scale, or a little more than twice that of a standard 7.5' quadrangle. The resolution at this scale is sufficient (although only barely) to read driver warnings such as "PED XING" painted on city streets. Vernal pools are readily apparent at this scale, as an irregularly dendritic array of gray to tan blobs in the golden brown of the summer grasslands in which the habitat occurs. Figure 1 shows a sample area near Corning.

Each slide covered roughly one mile north-south and about 1.4 miles east-west. Using a stack loader, it was a simple, though tedious, process to click through every slide in every flight line while tracking location on the topographic sheets. When habitat was found, I mapped it directly onto the quadrangles. Habitat density within each polygon was qualitatively scored as low, medium, or high using the attribute classes of Table 1. Ultimately, I examined somewhere over 40,000 slides covering part or all of 562 quadrangles covering the area below the conifer forests from Shasta Dam to Tehachapi Valley and west to the North Bay counties. The final study area is not known exactly, but probably approaches 18,000,000 acres. It includes all or part of 30 counties.

| Attribute Class | Characteristics |
|---|---|
| 0 | Cut-outs, e. g. a cultivated field surrounded by habitat. |
| 1 | Pools are small; widely and patchily scattered. At least 2 and usually 5 or more pools within the delineated vernal pool complex. |
| 2 | Pools are larger; more numerous and more pervasively scattered, although still patchy within the delineated vernal pool complex. |
| 3 | Pools are all sizes and numerous. Pools are distributed over the entire delineated vernal pool complex. Also includes large, isolated playa-like pools. |
| 4 | Pools are present and persist in spite of obvious cultivation, usually of hay crops. |
| 5 | Pools are present and still visible in spite of subdivision into "starve-your-horse-slowly" parcels smaller than minimum mapping size. |
| 6 | Not used. |
| 7 | Pools were present in earlier photos, but were gone in 1997 U2 flight. |
| 8 | As in Attribute Class 1, but with obvious signs of disturbance. |
| 9 | As in Attribute Class 2, but with obvious signs of disturbance. |

Table 1. Attribute class characteristics.

Craig Turner of DFG's Natural Heritage Division GIS staff digitized each quadrangle as mapping was completed. Check plots were compared with the manuscript quadrangles, flagging several errors for correction. These plots, together with the software, were ruthless in finding my mapping errors as well. These included about 40 "unclosed arcs", dangling line segments that went nowhere, and about two dozen polygons that lacked habitat density scores. Near the end of the project I returned to the slides and corrected all these errors.

The work summarized above lead to a new map of Great Valley vernal pool distribution, (Holland 1998), to which the reader is referred for salient details. New efforts undertaken for the present study are described below.

Once the data had been cleaned up, Craig Turner superimposed them on SPOT imagery available at NHD. SPOT is a proprietary French concern that provides satellite coverage for large parts of the world, including all of California. He printed these images on transparent media at 1:130,000 scale, matching that of a July, 1997 U2 flight that covered nearly the entire survey area. A sample print is shown in Figure 2. The U2 imagery had been obtained by NASA-Ames Research Center for the California Department of Conservation Farm Lands Mapping Program and consisted of about 1500 9-inch square transparencies in false color infrared. The images were acquired over four flights during mid July, 1997. Each transparency covered about 16 x 16 miles; there was 60 per cent overlap of adjacent frames. The registration between the U2 photos and the SPOT images was spectacular.

U2 imagery was considered but rejected for the initial mapping because vernal pools are not readily visible at its small scale (1:130,000). Changes such as agricultural or urban development are readily visible at 1:130,000, however, because they are such a change in land use from the low-intensity, dispersed grazing that is typical of surviving vernal pool habitat. Using a light table, it took only a few days to locate each polygon in the U2 photos. Any change in land use within a polygon was readily apparent and was mapped onto the SPOT imagery. These changes were redigitized, then check plots were compared with manuscript maps.

## 3. Results

When the initial mapping was presented in 1996 (Holland 1998), I had drawn 7,034.3 miles of polygon boundary around 1781 polygons that enclosed 1,027,067 acres. However, this includes 86 Attribute Class 0 polygons (cut-outs surrounded by habitat) totaling 11,803 acres. Thus, the habitat then known extant consisted of 1695 polygons totaling 1,015,264 acres. Polygons were mapped on 345 of the 562 quadrangles included in the survey area; half of these had three or fewer polygons. One quadrangle had 43 polygons. The single largest polygon represents 36,447 acres of high-density habitat that falls on five quadrangles in eastern Merced county.

Heritage Program GIS staff then cookie-cut out each county for planimetry. Because of polygons that straddled county lines, this artificially increased the number of polygons from 1695 to 1929. Table 2 summarizes by county the number and combined area of polygons within each density class as of the year of original photography and as of July 1997. Attribute Class 7 represents those polygons that apparently were lost over the interval between DWR and U2 photo dates. The data presented in Table 2 differ with those presented in 1996 for several reasons: 1) The 1998 planimetry used a newer, more accurate algorithm, 2) The 1998 planimetry accurately followed county lines, while the 1996 planimetry arbitrarily assigned all of each polygon that straddled a county line to the county that had the majority of the polygon, and 3) Edits and corrections in digitizing. The data presented here in Table 2 are much more accurate than those presented in 1996.

| COUNTY AND PHOTO YEAR | ATTRIBUTE CLASS | | | | | | | | | TOTAL |
|---|---|---|---|---|---|---|---|---|---|---|
| | 0 | 1 | 2 | 3 | 4 | 5 | 7 | 8 | 9 | |
| Alameda | | | | | | | | | | |
| 1986 polygons | | 7 | 4 | | | | | | | 11 |
| acres | | 1481 | 1271 | | | | | | | 2751 |
| 1997 polygons | | 5 | 4 | | | | 2 | | | 9 |
| acres | | 1133 | 1271 | | | | 348 | | | 2404 |
| Amador | | | | | | | | | | |
| 1983 polygons | | 11 | 5 | 1 | | | | | | 17 |
| acres | | 807 | 2685 | 581 | | | | | | 4073 |
| 1997 polygons | | 11 | 5 | 1 | | | | | | 17 |
| acres | | 807 | 2685 | 581 | | | | | | 4073 |
| Butte | | | | | | | | | | |
| 1994 polygons | 11 | 36 | 34 | 10 | | | | | | 80 |
| acres | 1248 | 23550 | 32315 | 3434 | | | | | | 59299 |
| 1997 polygons | 11 | 35 | 30 | 9 | | | 6 | | | 74 |
| acres | 1248 | 23461 | 31923 | 3359 | | | 555 | | | 58744 |
| Calaveras | | | | | | | | | | |
| 1983 polygons | 1 | 19 | 8 | 1 | | | | | | 28 |
| acres | 381 | 2633 | 3607 | 165 | | | | | | 6405 |
| 1997 polygons | 1 | 19 | 8 | 1 | | | | | | 28 |
| acres | 381 | 2633 | 3607 | 165 | | | | | | 6405 |
| Colusa | | | | | | | | | | |
| 1993 polygons | 2 | 28 | 4 | | | | | | | 32 |
| acres | 18 | 4917 | 810 | | | | | | | 5727 |
| 1997 polygons | 2 | 20 | 3 | | | | 9 | | | 23 |
| acres | 18 | 3701 | 677 | | | | 1348 | | | 4379 |
| Contra Costa | | | | | | | | | | |
| 1985 polygons | | 14 | 4 | 1 | | | | | | 19 |
| acres | | 2296 | 507 | 279 | | | | | | 3082 |
| 1997 polygons | | 14 | 4 | 1 | | | | | | 19 |
| acres | | 2296 | 507 | 279 | | | | | | 3082 |
| Eldorado | | | | | | | | | | |
| 1983 polygons | | 15 | | | | | | | | 15 |
| acres | | 1232 | | | | | | | | 1232 |
| 1997 polygons | | 15 | | | | | | | | 15 |
| acres | | 1232 | | | | | | | | 1232 |
| Fresno | | | | | | | | | | |
| 1994 polygons | 3 | 29 | 13 | 12 | 2 | | | | | 56 |
| acres | 240 | 13821 | 9604 | 4172 | 359 | | | | | 27955 |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| 1997 polygons | 3 | 29 | 10 | 10 | 2 | | 5 | | | 51 |
| acres | 240 | 13821 | 9186 | 4093 | 359 | | 496 | | | 27459 |
| Glenn | | | | | | | | | | |
| 1993 polygons | | 18 | 13 | | | | | | | 31 |
| acres | | 6109 | 4690 | | | | | | | 10799 |
| 1997 polygons | | 11 | 12 | | | | 8 | | | 23 |
| acres | | 4053 | 4058 | | | | 2688 | | | 8111 |
| Kern | | | | | | | | | | |
| 1990 polygons | | 8 | 2 | | | | | 8 | | 18 |
| acres | | 1644 | 669 | | | | | 5086 | | 7399 |
| 1997 polygons | | 6 | 2 | | | | 2 | 8 | | 16 |
| acres | | 1093 | 669 | | | | 551 | 5086 | | 6848 |
| Kings | | | | | | | | | | |
| 1991 polygons | 2 | 7 | 2 | 3 | | | | 10 | 3 | 25 |
| acres | 189 | 1409 | 358 | 4618 | | | | 2040 | 3236 | 11660 |
| 1997 polygons | 2 | 6 | 2 | 2 | | | 6 | 7 | 2 | 19 |
| acres | 189 | 1352 | 358 | 4541 | | | 377 | 1954 | 3078 | 11283 |
| Lake | | | | | | | | | | |
| 1995 polygons | | 35 | | | 2 | | | | | 37 |
| acres | | 2450 | | | 222 | | | | | 2672 |
| 1997 polygons | | 35 | | | 2 | | | | | 37 |
| acres | | 2450 | | | 222 | | | | | 2672 |
| Madera | | | | | | | | | | |
| 1987 polygons | 1 | 39 | 34 | 7 | 3 | | | | 1 | 84 |
| acres | 63 | 12689 | 70729 | 5945 | 452 | | | | 1363 | 91178 |
| 1997 polygons | 1 | 35 | 28 | 5 | 2 | | 13 | | 1 | 71 |
| acres | 63 | 11564 | 68445 | 5228 | 446 | | 4130 | | 1363 | 87047 |
| Marin[1] | | | | | | | | | | |
| 1986 polygons | | 2 | | | | | | | | 2 |
| acres | | 262 | | | | | | | | 262 |
| 1997 polygons | | 2 | | | | | | | | 2 |
| acres | | 262 | | | | | | | | 262 |
| Mariposa | | | | | | | | | | |
| 1976 polygons | 1 | 7 | 8 | 6 | | | | | | 21 |
| acres | 19 | 2370 | 3627 | 550 | | | | | | 6547 |
| 1997 polygons | 1 | 7 | 8 | 6 | | | | | | 21 |
| acres | 19 | 2370 | 3627 | 550 | | | | | | 6547 |
| Merced | | | | | | | | | | |
| 1987 polygons | 13 | 97 | 76 | 36 | 21 | 1 | | | | 231 |
| acres | 2805 | 68584 | 139430 | 72025 | 2486 | 216 | | | | 282741 |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| 1997 polygons | 13 | 83 | 64 | 32 | 19 | 1 | 32 | | | 199 |
| acres | 2805 | 65081 | 113398 | 71376 | 2351 | 216 | 30317 | | | 252424 |
| Napa | | | | | | | | | | |
| 1987 polygons | 1 | 6 | 2 | | | | | | | 8 |
| acres | 19 | 681 | 624 | | | | | | | 1304 |
| 1997 polygons | 1 | 5 | 1 | | | | 2 | | | 8 |
| acres | 19 | 667 | 411 | | | | 226 | | | 1078 |
| Placer | | | | | | | | | | |
| 1994 polygons | 16 | 50 | 32 | 18 | 4 | | | | | 104 |
| acres | 1378 | 10715 | 28424 | 7673 | 1529 | | | | | 48341 |
| 1997 polygons | 15 | 46 | 28 | 15 | 4 | | 12 | | | 93 |
| acres | 1342 | 10307 | 27527 | 7489 | 1529 | | 1525 | | | 46852 |
| Sacramento | | | | | | | | | | |
| 1993 polygons | 1 | 138 | 53 | 9 | 3 | | | | | 203 |
| acres | 26 | 22417 | 12621 | 17691 | 255 | | | | | 52985 |
| 1997 polygons | 1 | 134 | 53 | 9 | 3 | | 4 | | | 196 |
| acres | 26 | 22202 | 12621 | 17691 | 255 | | 215 | | | 52770 |
| San Joaquin | | | | | | | | | | |
| 1988 polygons | 17 | 92 | 52 | 24 | | | | | | 168 |
| acres | 2597 | 18915 | 10430 | 7714 | | | | | | 37059 |
| 1997 polygons | 17 | 87 | 43 | 21 | | | 17 | | | 151 |
| acres | 2597 | 18409 | 9675 | 7379 | | | 1595 | | | 35463 |
| Shasta | | | | | | | | | | |
| 1995 polygons | 1 | 53 | 6 | 9 | | | | | | 68 |
| acres | 27 | 13392 | 1605 | 9283 | | | | | | 24280 |
| 1997 polygons | 1 | 51 | 6 | 7 | | | 4 | | | 64 |
| acres | 27 | 13262 | 1605 | 9199 | | | 214 | | | 24066 |
| Solano | | | | | | | | | | |
| 1994 polygons | 7 | 44 | 16 | 1 | | | | | | 61 |
| acres | 1105 | 12494 | 8113 | 18271 | | | | | | 38878 |
| 1997 polygons | 7 | 41 | 12 | 1 | | | 7 | | | 61 |
| acres | 1105 | 11765 | 7308 | 18271 | | | 1534 | | | 37344 |
| Sonoma | | | | | | | | | | |
| 1986 polygons | | 39 | 20 | 1 | | | | | | 60 |
| acres | | 2437 | 1986 | 54 | | | | | | 4477 |
| 1997 polygons | | 35 | 18 | 1 | | | 6 | | | 60 |
| acres | | 2109 | 1544 | 54 | | | 770 | | | 3707 |
| Stanislaus | | | | | | | | | | |
| 1988 polygons | 7 | 69 | 59 | 18 | 7 | | | | | 153 |
| acres | 639 | 63300 | 20125 | 6878 | 1727 | | | | | 92031 |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| 1997 polygons | 7 | 65 | 53 | 17 | 7 | | 11 | | | 142 |
| acres | 639 | 62463 | 19639 | 6784 | 1728 | | 1418 | | | 90613 |
| Sutter | | | | | | | | | | |
| 1990 polygons | | 21 | 4 | | | | | | | 25 |
| acres | | 1035 | 329 | | | | | | | 1364 |
| 1997 polygons | | 21 | 3 | | | | 1 | | | 24 |
| acres | | 1035 | 259 | | | | 70 | | | 1294 |
| Tehama | | | | | | | | | | |
| 1994 polygons | 1 | 122 | 44 | 17 | 3 | | | | 1 | 187 |
| acres | 128 | 82472 | 41226 | 13586 | 600 | | | | 43 | 137927 |
| 1997 polygons | 1 | 115 | 39 | 15 | 3 | | 14 | | 1 | 173 |
| acres | 128 | 80994 | 40961 | 12162 | 600 | | 3167 | | 43 | 134760 |
| Tulare | | | | | | | | | | |
| 1993 polygons | 4 | 44 | 15 | 12 | | | | 15 | 6 | 92 |
| acres | 766 | 4246 | 6832 | 20922 | | | | 3238 | 1669 | 36907 |
| 1997 polygons | 4 | 39 | 15 | 11 | | | 11 | 12 | 4 | 81 |
| acres | 766 | 3711 | 6832 | 20837 | | | 2006 | 2031 | 1489 | 34900 |
| Tuolumne | | | | | | | | | | |
| 1976 polygons | | 9 | 4 | | | | | | | 13 |
| acres | | 846 | 3142 | | | | | | | 3988 |
| 1997 polygons | | 9 | 4 | | | | | | | 13 |
| acres | | 846 | 3142 | | | | | | | 3988 |
| Yolo | | | | | | | | | | |
| 1989 polygons | | 22 | 1 | | | | | | | 23 |
| acres | | 3264 | 389 | | | | | | | 3652 |
| 1997 polygons | | 14 | 1 | | | | 8 | | | 15 |
| acres | | 2292 | 389 | | | | 971 | | | 2681 |
| Yuba | | | | | | | | | | |
| 1995 polygons | | 36 | 7 | 4 | | | | | | 47 |
| acres | | 6807 | 3863 | 1559 | | | | | | 12229 |
| 1997 polygons | | 33 | 7 | 3 | | | 4 | | | 43 |
| acres | | 6505 | 3863 | 1503 | | | 358 | | | 11871 |
| | | | | | | | | | | |
| DWR polygons | 98 | 1115 | 527 | 196 | 45 | 1 | 0 | 33 | 12 | 1929 |
| DWR acres | 11649 | 389273 | 410010 | 195399 | 7631 | 216 | 0 | 10365 | 6311 | 1019204 |
| 1997 U2 polygons | 89 | 1026 | 468 | 173 | 42 | 1 | 184 | 27 | 10 | 1747 |
| 1997 U2 acres | 11613 | 373877 | 376187 | 191543 | 7490 | 216 | 54882 | 9072 | 5973 | 964358 |

Table 2. Number (above) and collective area (acres, below, rounded) of polygons within habitat density classes in each mapped county as of that county's photo date and after updating to 1997 U2 imagery. These data differ somewhat from those in Holland 1998

because of more precise planimetry and more accurate treatment of those polygons that straddled county lines. Cutouts (Attribute Class 0) and lost habitat (Attribute Class 7) have been removed from the totals.

Valley-wide, 184 polygons covering 54,882 acres disappeared in the interval between DWR and U2 flights. No changes were noted in eight counties: Amador, Calaveras, Contra Costa, Eldorado, Lake, Marin, Mariposa, Tuolumne. Habitat losses in the remaining counties ranged from a single Attribute Class 2 polygon covering 70 acres in Sutter County to 32 polygons covering 30,317 acres in Merced County. Table 3 provides 3 expressions of habitat loss rate by county. Apparent trends in each county are described in the following paragraphs.

| **County & DWR photo date** | **Loss rate since DWR photo date, expressed as** | | |
|---|---|---|---|
| | **Acres per year** | **Percent loss over interval** | **Percent loss per year** |
| Alameda 1986 | 31.6 | 12.6 | 1.1 |
| Amador 1983 | 0.0 | 0.0 | 0.0 |
| Butte 1994 | 185.0 | 0.9 | 0.3 |
| Calavaras 1983 | 0.0 | 0.0 | 0.0 |
| Colusa 1993 | 337.0 | 23.5 | 5.9 |
| Contra Costa 1985 | 0.0 | 0.0 | 0.0 |
| Eldorado 1983 | 0.0 | 0.0 | 0.0 |
| Fresno 1994 | 165.3 | 1.8 | 0.6 |
| Glenn 1993 | 672.0 | 24.9 | 6.2 |
| Kern 1990 | 78.7 | 7.4 | 1.1 |
| Kings 1991 | 62.8 | 3.2 | 0.5 |
| Lake 1995 | 0.0 | 0.0 | 0.0 |
| Madera 1987 | 413.0 | 4.5 | 0.4 |
| Marin 1986 | 0.0 | 0.0 | 0.0 |
| Mariposa 1976 | 0.0 | 0.0 | 0.0 |
| Merced 1987 | 3031.7 | 10.7 | 1.1 |
| Napa 1987 | 22.6 | 17.3 | 1.7 |
| Placer 1994 | 508.3 | 3.1 | 1.0 |
| Sacramento 1993 | 53.7 | 0.4 | 0.1 |
| San Joaquin 1988 | 177.2 | 4.3 | 0.5 |
| Shasta 1995 | 107.0 | 0.9 | 0.4 |
| Solano 1994 | 511.3 | 3.9 | 1.3 |

| | | | |
|---|---|---|---|
| Sonoma 1986 | 70.0 | 17.2 | 1.6 |
| Stanislaus 1988 | 157.5 | 1.5 | 0.2 |
| Sutter 1990 | 10.0 | 5.1 | 0.7 |
| Tehama 1994 | 1055.6 | 2.3 | 0.7 |
| Tulare 1993 | 501.5 | 5.4 | 1.4 |
| Tuolumne 1976 | 0.0 | 0.0 | 0.0 |
| Yolo 1989 | 121.3 | 26.6 | 3.3 |
| Yuba 1995 | 179.0 | 2.9 | 1.4 |

Table 3. Observed losses of vernal pool complexes by County over the period between DWR photo dates and July, 1997. These rates are derived from Table 2 and express losses for the interval as acres per year, the percent of habitat extant as of the DWR photo date that disappeared by July 1997, and as percent lost per year.

Alameda County was mapped from 1986 DWR slides. In the intervening 11 years only two polygons covering 348 acres disappeared, or slightly over 30 acres/year This amounts to over 12 percent decrease in habitat over the interval, or about 1.1 percent per year.

No changes in habitat extent were noted in Amador County.

Butte County was mapped from 1994 DWR slides. In the intervening 3 years 6 polygons covering 555 acres disappeared, or 185 acres per year. This is almost a percent decrease over the interval, or about 0.3 percent per year.

No changes in habitat extent were noted in Calavaras County

Colusa County was mapped from 1993 DWR slides. In the intervening 4 years 9 polygons covering 1,348 acres disappeared, or 337 acres per year. This is over a 23 percent decrease over the interval, or nearly 6 percent per year. Only Glenn County has a higher loss rate when expressed as percent per year.

No changes in habitat extent were noted in Contra Costa County

No changes in habitat extent were noted in Eldorado County.

Fresno county was mapped from 1994 DWR slides. In the intervening 3 years 5 polygons covering 496 acres disappeared, or about 165 acres per year. This is a 1.8 percent decrease over the interval, or 0.6 percent per year.

Glenn County was mapped from 1993 DWR slides. In the intervening 4 years 8 polygons covering 2,688 acres disappeared, or about 672 acres per year. This is very nearly a 25 percent decrease over the interval, second only to Yolo County. Glenn County's annualized loss rate (6.2 percent per year) exceeds that observed in any other county.

Kern County was mapped from 1990 DWR slides. In the intervening 7 years, 2 polygons covering 551 acres disappeared, or about 79 acres per year. This is over a 7 percent decrease over the interval, or 1.1 percent per year.

Kings County was mapped from 1991 DWR slides. In the intervening 6 years, 6 polygons covering 377 acres disappeared, or nearly 63 acres per year. This is a 3.2 percent decrease over the interval, or 0.5 percent per year.

No changes in habitat extent were noted in Lake County.

Madera County was mapped from 1987 DWR slides. In the intervening 10 years 13 polygons covering 4,130 acres disappeared, or 413 acres per year. This is a 4.5 percent decrease over the interval, or 0.4 percent per year.

No changes in habitat extent were noted in Marin County. It should be noted that Marin County coverage was limited to overflight from adjacent Sonoma County: only a portion of northern Marin County was mapped.

No changes in habitat extent were noted in Mariposa County.

Merced County was mapped from 1987 DWR slides. In the intervening 10 years 32 polygons covering 30,317 acres disappeared, or nearly 3,032 acres per year. More than half of all habitat loss observed in this study was in Merced County. This is a 10.7 percent loss over the interval, or 1.1 percent per year.

Napa County was mapped from 1987 DWR slides. In the intervening 10 years 2 polygons covering 226 acres disappeared, or 22.6 acres per year. This is a 17.3 percent loss over the interval, or 1.7 percent per year.

Placer County was mapped from 1994 DWR slides. In the intervening 3 years 12 polygons covering 1,525 acres disappeared, or over 508 acres per year. This is a 3.1 percent drop over the interval, or just over 1 percent per year.

Sacramento County was mapped from 1993 DWR photos. During much of the intervening 4 years, Sacramento County had imposed a moratorium on new real estate development projects, so only 4 polygons covering 215 acres disappeared. This is a 0.4 percent decrease over the interval, or only 0.1 percent per year. However, Holland (1988) provides data indicating that over the interval from 1972 to 1993 some 30,512 acres disappeared, or over 1,450 acres per year, averaged over a much longer and more representative period. This is 36 percent decrease over the interval, or 1.7 percent per year.

San Joaquin County was mapped from 1988 DWR slides. In the intervening 9 years 17 polygons covering 1,595 acres disappeared, or over 177 acres per year. This is a 4.3 percent decrease over the interval, or about 0.5 percent per year.

Shasta County was mapped from 1995 DWR slides. In the intervening 2 years 4 polygons covering 214 acres disappeared, or 107 acres per year. This is almost a 1 percent decrease over the interval, or about 0.4 percent per year.

Solano county was mapped from 1994 DWR slides. In the intervening 3 years 7 polygons covering 1,534 acres disappeared, or over 511 acres per year. This is nearly a 4 percent decrease over the interval, or 1.3 percent per year.

Sonoma County was mapped from 1986 DWR slides. In the intervening 11 years 6 polygons covering 770 disappeared, or 70 acres per year. This is a 17.2 percent decrease over the interval, or 1.6 percent per year.

Stanislaus County was mapped from 1988 DWR slides. In the intervening 9 years 11 polygons covering 1,418 acres disappeared, nearly 158 acres per year. This is a 1.5 percent decrease over the interval, or 0.2 percent per year.

Sutter County was mapped form 1990 DWR slides. In the intervening 7 years 1 polygon covering 70 acres disappeared. This is a 5.1 percent decrease over the interval, or 0.7 percent per year.

Tehama County was mapped from 1994 DWR slides. In the intervening 3 years 14 polygons covering 3,167 acres disappeared, over 1,055 acres per year. This is a 2.3 percent decrease over the interval, or 0.7 percent per year.

Tulare County was mapped from 1993 DWR slides. In the intervening 4 years 11 polygons covering 2,006 acres disappeared, over 501 acres per year. This is a 5.4 percent decrease over the interval, or 1.4 percent per year.

No changes in habitat extent were noted in Tuolumne County.

Yolo County was mapped from 1989 DWR slides. In the intervening 8 years, 8 polygons covering 971 acres disappeared, over 121 acres per year. This is a 26.6 percent decrease over the interval, the highest observed in the entire study, or 3.3 percent per year.

Yuba county was mapped from 1995 DWR slides. In the intervening 2 years 4 polygons covering 358 acres disappeared, or 179 acres per year. This is a 2.9 percent decrease over the interval, or 1.4 percent per year.

## 4. Discussion

The eight counties in which no losses were noted (Amador, Calavaras, Contra Costa, Eldorado, Lake, Marin, Mariposa, Tuolumne) all are foothill or Coast Range counties that barely encroach upon vernal pool landscapes. Collectively, these eight counties account for less that 2.5 percent of the habitat extant in July, 1997.

Higher density polygons tended to be larger: Attribute Class 1 polygons average 350 acres apiece; Class 2 polygons average 779 acres, and Class 3 polygons average 1,000 acres. Similar increases are evident in the disturbed classes, 8 and 9.

In every county, the average size of each polygon increased about 1.4 percent over the interval since DWR photos. This suggests that losses are preferentially focused on smaller polygons that are entirely converted.

The 22 counties in which habitat losses were noted averaged 384 acres lost per year per county, but this was very unevenly distributed. As mentioned above, only 70 acres disappeared from Sutter County over a 7-year period, while over 30,000 acres disappeared from Merced County over 10 years. It is more telling to express habitat loss as percent lost per year, thereby facilitating comparisons among counties. Seen this way, habitat loss was most rapid in Colusa and Glenn counties (5.9 and 6.2 percent per year, respectively), high in Yolo County (3.3 percent per year) and near 1.4 percent per year over all. This over-all estimate is somewhat lower than the 2-3 percent per year reported in Holland (1988). This difference may reflect the increased precision of the present study, or the slow down in the building industry induced by the economic contractions of the late 1980s and early 1990s, or increasingly effective regulation.

By July, 1997, extant vernal pool landscapes throughout the Great Valley had fallen below 1,000,000 acres. Holland (1978) estimated that roughly 4,000,000 acres of vernal pool habitat existed in pre-agricultural time, suggesting that roughly three quarters of the original habitat has been lost. These losses have continued even over the past decade, in spite of considerable regulatory activity, political wrangling, and litigation. More than 5 percent of the habitat I mapped from the DWR slides had disappeared by 1997. Even at a loss rate of only 1.5 percent per year, 1,000,000 acres will have shrunk by half in just 46 years, down to about 12 percent of the original area. It is hard to imagine how these ecosystems can be expected to function normally in the face of an 88 percent reduction in extent. By analogy, how would a citizen feel who saw 88 percent of his assets appropriated?

## 5. Acknowledgments

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Figure 1. Air photo mosaic of an area west of Corning in Tehama County, printed here at nominal 1:24,000 scale with polygon boundaries superimposed. Numbers within polygons correspond to attribute classes of Table 1.

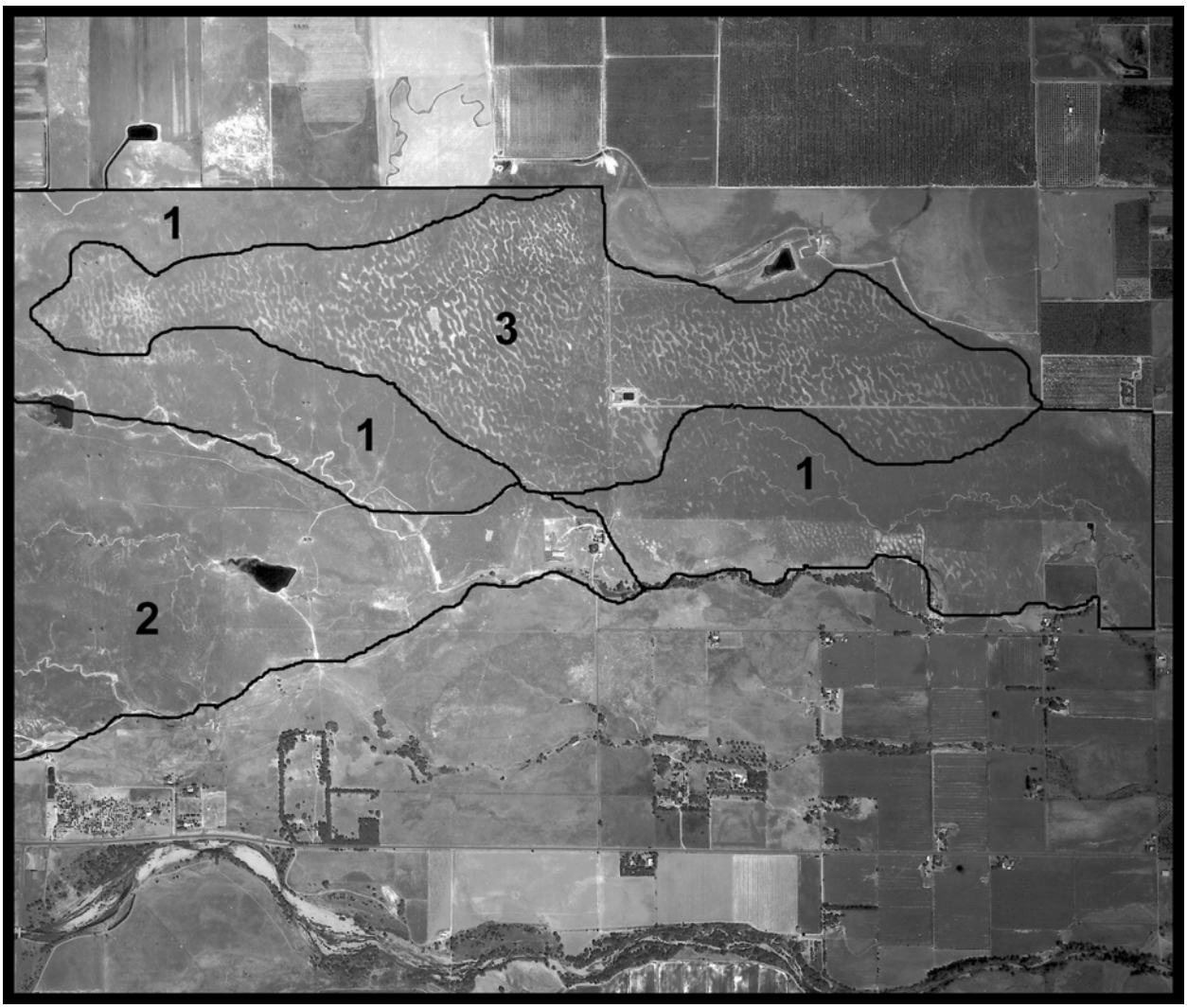

Figure 2. Mapped polygon boundaries superimposed on SPOT image of part of Merced and Madera County, centered over the Chowchilla River, printed here at nominal 1:130,000 scale. Note how some polygon boundaries follow natural features, while others are culturally imposed. Diagonally dashed pattern indicates 5 polygons converted from dispersed grazing to more intensive uses.

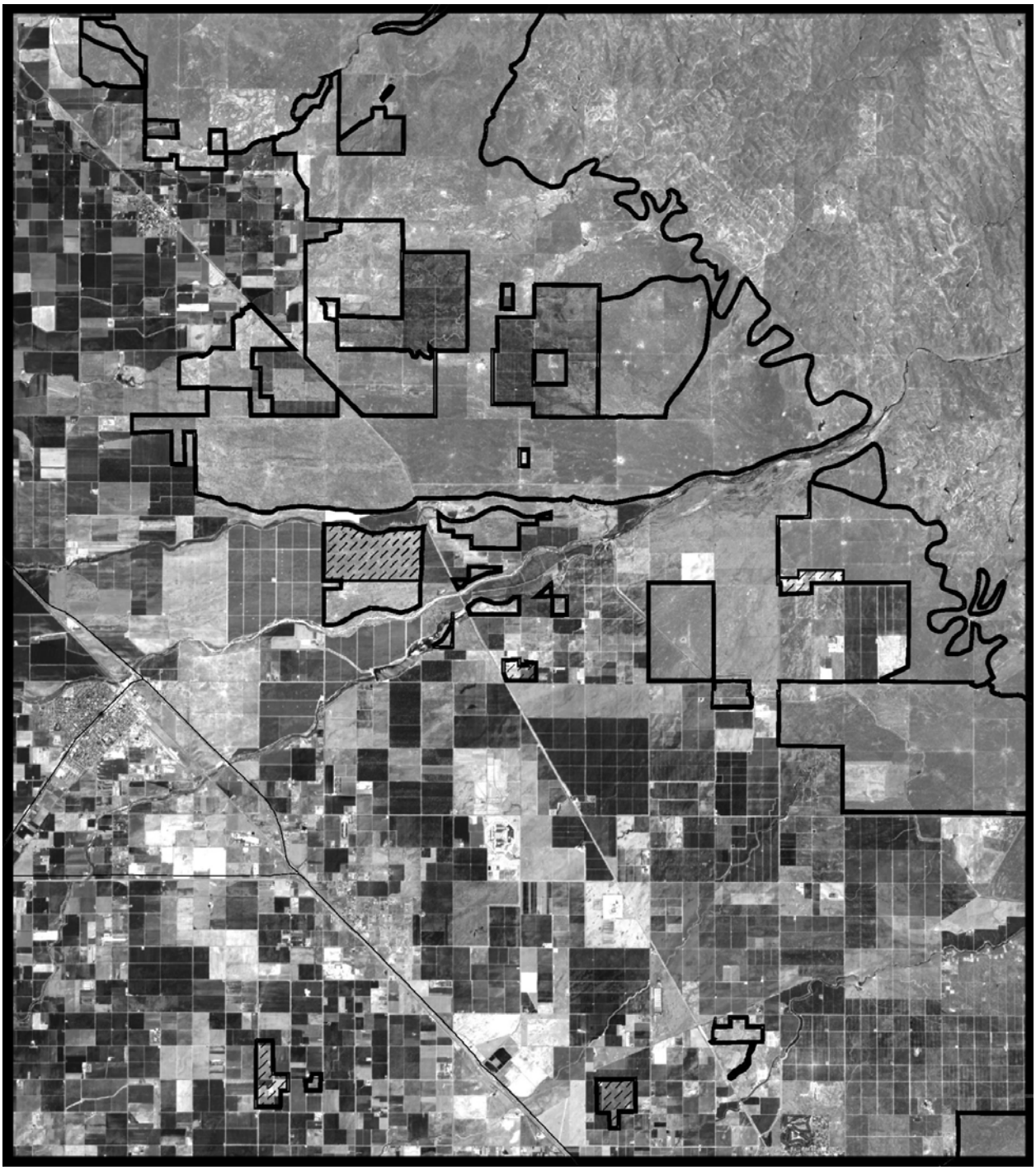

Figure 3. Map of the Holland Study Area, and Vernal Pool Density Classes.